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Sequestration of C in a Spanish chestnut coppice

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Abstract

The balance of C is one of the most important balances in nature, since it determines the flow of organic matter, governs that of other bioelements (N, P, S, etc.), and controls the content of CO_2 in the atmosphere. The objective of this work was to quantify the C sequestration in a Sweet chestnut forest located in the «*Sierra de Gata*» Mountains (Central-Western Spain). This chestnut coppice is located in the south edge of the «*Sierra de Gata*» mountains (province of Cáceres, central-western Spain). Climatic characteristics are mean temperature 15 ºC and mean annual-rainfall 1,158 mm yr^{-1}, i. e., sub-humid Mediterranean. The soils are an association of *haplic Umbrisols* and *Leptosols*. This coppice of *Castanea sativa* is 25 years old, i. e., the usual rotation time. The accumulations of C in the tree biomass was 58 Mg C ha^{-1} yr^{-1}, the calculated litter decomposition-constants 0.39 yr^{-1}, and the aboveground annual-production 5.25 Mg C ha^{-1} yr^{-1}. The accumulation of C in the Ah horizons was 143 Mg C ha^{-1}. On calculating a global balance, inputs of C into this forest ecosystem are always greater than the C outputs, the excess being 4.7 Mg C ha^{-1} yr^{-1}.

Key words: C sequestration, coppice, western Spain, soil organic matter, *Castanea sativa*, sweet chestnut.

Resumen

Capacidad de captura de C de un castañar del Oeste español

Uno de los balances más importantes de la Naturaleza es el del C, puesto que determina el flujo de materia orgánica y, también en gran parte, el de otros bioelementos (N, P, S, etc.), además de controlar el contenido de CO_2 en la atmósfera. El objetivo de este trabajo fue cuantificar la captura de C producida en un castañar (Monte bajo) situado en la Comarca de la «Sierra de Gata» (provincia de Cáceres, Centro Oeste español). El clima es mediterráneo subhúmedo, con una temperatura media de 15 ºC y una pluviometría media anual de 1.158 mm a^{-1}. Los suelos se clasifican como asociación de *Umbrisoles háplicos* y *Leptosoles*. El castañar (*Castanea sativa*) se gestiona como Monte bajo, teniendo una edad de 25 años, que suele ser la del turno. La acumulación de C in la biomasa de los árboles es de 58 Mg C ha^{-1} a^{-1}; la constante de descomposición de la hojarasca 0.39 a^{-1}; y la producción aérea anual 5.25 Mg C ha^{-1} a^{-1}. La acumulación de C en el horizonte edáfico Ah es de 143 Mg C ha^{-1}. Si se realiza un balance total en este bosque las entradas de C son siempre mayores que las salidas y se cuantifica la diferencia en 4.7 Mg C ha^{-1} a^{-1}.

Palabras clave: captura de C, monte bajo, oeste de España, materia orgánica del suelo, *Castanea sativa,* castaño.

Introduction and objetive

One of the most important balances in nature is that of carbon, since it determines the flow of organic matter and it also governs that of other bioelements (N, P, S, etc.; Schlesinger, 1995). The importance of the C cycle has recently increased, mainly in the matter of how to avoid climate change, the current direction of which is supposed to be leading to an increase in the global temperature (according to the Kyoto Protocol; Hagedorn *et al.,* 2000), by fixing C in soils (Swift, 2001) and biomass (Deward & Cannel, 1992). This C sequestration might affect the C cycle (and related bioelement cycles; Arp *et al.,* 1997), since that diminishes the content of CO_2 in the atmosphere (Díaz Balteiro & Romero, 2001; Rees *et al.,* 2001).

Batjes (1999) pointed out that, for estimating the potentiality of C sequestration in ecosystems, two questions should be previously addressed: First at all, what is the original content of the climax or natural soil in soil C; and, secondly, what are the changes induced by the management on soil and soil organic-C (SOC) content. That means that data on the original SOC contents in natural soils are necessary in addition to data of the current SOC contents in agricultural soils

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studied which we want to improve. Anyway, the method for estimating the C sequestration by soil should take in account the C content (in mg C g^{-1}), horizon depths (in cm), density (in Mg m^{-3}), and stoniness (in %) of the different soil horizons; the results are expressed in Mg ha^{-1} and referred to an indicated soil depth.

In addition, chestnut coppices are forest systems very well distributed in Spain (Rubio & Gandullo, 1994a; Gallardo, 2001), mainly in Asturias (Rubio & Gandullo, 1994a), Catalunya (Rubio *et al.,* 1999), and Extremadura (Rubio & Gandullo, 1994b; Rubio *et al.,* 1997), besides other Spanish districts.

In the idea to know the capacity of C sequestration of different Spanish ecosystems, the objective of this work was to quantify the C sequestered in a selected, well studied, Spanish chestnut coppice located in the «*Sierra de Gata*» Mountains (Central-Western Spain).

Environment and site description

The study stand is located the south edge of the «*Sierra de Gata*» mountains (province of Cáceres, central-western Spain; Martin *et al.,* 1995; Gallardo *et al.,* 1997). This Spanish district is located close to the Portuguese border. The selected chestnut forest belongs to the municipality of San Martín de Trevejo (SMT: 610 m a. s. l.; mean annual temperature 15.1 ºC; mean annual precipitation, 1,158 mm yr^{-1}). The selected coppice site is almost at the summit of the range (South side; 940 m a.s.l.). The climate of this district is sub-humid Mediterranean (the length of the summer drought usually is shorter than three months).

Soils are mostly an association of *haplic Umbrisols* and *Leptosols*, according to F.A.O.'s soil units (Gallardo *et al.,* 1998a, 1998b). These soils are acid (Table 1) and have usually a base saturation lower than 25% in the soil profile.

Table 1. General characteristics of the forest site

Parameters	Units	SMT
Altitude a. s. l.	(m)	940
Mean annual rainfall	(mm/yr)	1,158
Annual rainfall (1993)	(mm/yr)	1,381
Mean temperature	(º C)	15.1
Throughfall (1993)	(mm/yr)	719
Superficial runoff	(mm/yr)	136
pH (H_2O) of the soil Ah horizon	(–)	5.1
Soil base saturation	(%)	10

SMT: San Martín de Trevejo site.

The stand is a Sweet chestnut (*Castanea sativa*) coppice, 25 years old after clear cutting; the coppice cycle (rotation time) of these Spanish chestnut coppices is usually about 25 years indeed.

Some general characteristics of this chestnut stand here indicated are given in Table 1. A distribution of the rainwater throughout the ecosystem is given by Moreno *et al.* (1994) and Gallardo *et al.* (1995).

Methods

— *C determination.* C in organic tissues and soils has been determined (Martín *et al.,* 1995) by a Carmhograph (Wosthöff) and C in water solutions by a total organic-C analyzer (Shimadzu).

— *Inputs of C by bulk rainfall.* The water rainfall was recovered in lysimeters, its volume measured approximately when rains occurred, and the C content determined in water samples (Moreno *et al.,* 1994; Gallardo *et al.,* 1995).

— *Annual tree growth.* Every year the increase of both tree diameter (DBH) and height (h) is measured and the means of at least 9 tree measures were considered (Gallego *et al.,* 1993; Leonardi *et al.,* 1996). From these data the annual C-sequestration as biomass was calculated.

— *Aboveground production.* The aboveground production was determined by recovering the litter produced in at least 30 boxes located at random in the forest (Martín *et al.,* 1995; Gallardo *et al.,* 1998a).

— *Litter decomposition constant.* Litter decomposition experiments were performed following the litterbag method (Gallardo *et al.,* 1997, 1998b).

— *C losses by runoff and deep drainage.* The water runoff was measured by Gerlach-type lysimeters. The water recovered in soil lysimeters at –85 cm depth was also measured. All the water samples were analysed (Moreno *et al.,* 1994; Gallardo *et al.,* 1995).

Results

Results are given in Tables 2 to 4. Table 2 shows the more important features of the selected coppice stand. Table 3 includes the C sequestrated by soils as practically stable organic C. In Table 4 fluxes throughout the forest ecosystem of C can be followed.

Aboveground biomass

Permanent biomass is about 117 Mg ha^{-1} in SMT (Table 2), with annual increase of tree diameter is close to 0.3 cm. The accumulation of C in the tree biomass is 58 Mg C ha^{-1} yr^{-1} (Gallego *et al.,* 1994; Leonardi *et al.,* 1996). C fixed annually by biomass, because of the growth of trunks, was calculated to be 5.7 Mg C ha^{-1} yr^{-1} (Table 2).

Litter production

The annual productions of litter, in terms of C (Table 2), is 2.55 Mg C ha^{-1} yr^{-1} at SMT (Gallardo *et al.,* 1998a).

Necromass

Since the litter decomposition constant, determined by litterbags, is 0.39 yr^{-1} (Table 2; Gallardo *et al.,* 1995, 1997), the calculated annual releases of C evolved to the atmosphere is 0.95 Mg C ha^{-1} yr^{-1} (Table 4). There is no continuous, permanent litter on the soil during the year, but mainly by winter.

Table 2. Characteristics of the study stand

Parameters	Units	SMT
Tree density	(trees/ha)	4,573
Mean heigth of trees	(m)	11.3
Mean diameter of trees (at 1.3 m)	(mm)	96
Basal aerea	(m^2/ha)	32
Total biomass	(Mg/ha)	117
C sequestered permanently by biomass	(MgC/ha)	58
Annual diameter growth	(mm/yr)	3.0
Mean annual increase of trunk volume	(m^3/ha, yr)	16
C sequestration by annual tree growth	(Mg C/ha, yr)	5.7
Aboveground annual production	(Mg/ha, yr)	5.25
Aboveground-C annual production	(Mg C/ha, yr)	2.55
Leaf annual production	(Mg/ha, yr)	3.43
Litter decomposition constant	(1/yr)	0.39
Soil litter (before litterfall)	(Mg/ha)	7.20

SMT: San Martín de Trevejo site.

Table 3. C sequestered in soil

Parameters	Profundidad (cm)	Units	SMT
Organic C in the Ah1 horizon	0-20	(Mg C/ha)	70
Organic C in the Ah2 horizon	20-50	(Mg C/ha)	73
Organic C in the Bw horizon	50-80	(Mg C/ha)	52
Total C sequestered in soil	0-85	(Mg C/ha)	195
Mineralization constant (Ah horizon)	0-85	(1/yr)	0.026

SMT: San Martín de Trevejo site.

Soil organic C (SOC)

The accumulation of C by the soil (Table 3) is 195 Mg C ha^{-1} (Gallardo *et al.,* 1995). The calculated constant of mineralisation of this soil C is quite low (0.026 yr^{-1}) and it is supposed that, if an equilibrium exists, the quantity of C evolved yearly toward the atmosphere (as CO_2) is practically equal to the new inputs of C through decomposing litter. The soil horizon Ah contains more than 70% of the total soil C (Table 3), giving rise to a C content (with reference to a –50 cm depth) of 143 Mg C ha^{-1}. Table 3 also indicates the values of C contents with reference to the variable depths of the horizons Ah in the three soils.

Fluxes of dissolved organic C (DOC)

— *Inputs.* The annual inputs of DOC to the ecosystem (Table 4) by means of rainwater was 50 kg C ha^{-1} yr^{-1} (Moreno *et al.,* 1994; Gallardo *et al.,* 1995). These inputs increase when the rainwater crosses through the forest canopy, giving as a result inputs to soil of 91 kg C ha^{-1} yr^{-1} by throughfall waters.

— *Outputs.* The estimated annual losses of DOC caused by deep drainage is 14 kg C ha^{-1} yr^{-1} (Gallardo *et al.,* 1995). In addition, a loss of C by surface runoff of 120 kg C ha^{-1} yr^{-1} should be added in SMT. Then, the estimated total DOC output is 134 kg C ha^{-1} yr^{-1} at SMT (Table 4).

Balance of C: C sequestered and C evolved

For the C balance, the total input and output of C must be considered. Table 4 shows the input value (5.8

Table 4. C fluxes and total budget in the chestnut coppice

Parameters	Units	SMT
Annual DOC inputs by rainfall	(kg C/ha, yr)	50
DOC inputs to soil by throughfall	(kg C/ha, yr)	91
C sequestration by annual tree growth	(Mg C/ha, yr)	5.7
Total C inputs to the forest system	(Mg C/ha, yr)	5.8
Annual C output by litter decomposition	(Mg C/ha, yr)	0.95
Annual C inputs to soil by litter	(Mg C/ha, yr)	0.68
Annual DOC loss by water runoff	(Kg C/ha, yr)	120
Annual DOC loss by C deep drainage	(Kg C/ha, yr)	14
Total C outputs from forest ecosystems	(Mg C/ha, yr)	1.1
Total annual balance of C in forest ecosystems (net inputs)	(Mg C/ha, yr)	4.7

SMT: San Martín de Trevejo site.

Mg C ha^{-1} yr^{-1}) taking into account the C fixed by permanent biomass, and the output value (1,080 kg C ha^{-1} yr^{-1}), including the C evolved by mineralisation. Then, the difference is 4.72 Mg C ha^{-1} yr^{-1} at SMT.

Discussion

Total C permanently sequestered

Obviously, the C permanently sequestered in soil is the main pool of C; this fact is very well known (Stevenson & Cole, 1999; Swift, 2001).

Adding this soil C content (Table 3) to the fixed C in the permanent biomass (Table 2) the result obtained gives the potentiality of C sequestration of this chestnut coppice. Thus, 312 Mg C ha^{-1} is, more or less permanently, fixed by the coppice stand here studied. Nevertheless, this value is of limited interest, because the permanent biomass is largely a function of forest management (as an example, lengthening of time-rotation; Rubio & Escudero, 2003). If the rotation time for that coppice biomass is supposed to be 25 years, then only a mean of about 468 kg C ha^{-1} yr^{-1} should be considered as a yearly increment of permanent biomass in the coppice if it is finally cleared off. This value is negligible considering the permanent C sequestered by soil (Table 3), but it is necessary to consider that the final destination of the chestnut wooden is as permanent logs or furnitures, not to be burned (fuel purpose); thus, the permanent C-sequestration is guaranteed.

Nevertheless, that value of 312 Mg ha^{-1} of sequestered C is high comparing to those of 116, 99, and 91 Mg C ha^{-1} estimated for deciduous oak (*Quercus pyrenaica*) coppices located at Navasfrías, Villasrubias, and Fuenteguinaldo, respectively (Northern slope of the «*Sierra de Gata*» mountains (province of Salamanca; Gallardo, data not published).

Annual biomass increase

Regarding annual biomass increase, it would be more interesting to know how much C could be fixed in this ecosystem every year.

The order of total, annual C-sequestration, obtained by adding the annual C fixed by permanent biomass (5.7 Mg C ha^{-1} yr^{-1}; Table 4) plus the residual C in litter production (680 kg C ha^{-1} yr^{-1}; Table 4), is 6.4 Mg C ha^{-1} yr^{-1}. This is the maximum of C that is annually sequestered by this coppice.

This relatively poor result is a consequence of the acid rock-material (Palaeozoic) dominant in the «*Sierra de Gata*» district (Martín *et al.,* 1995), which yields acid, poor soils. Furthermore, rainfall and runoff (slopes frequently higher than 30%) permit that acidification remains in these deciduous forest ecosystems (Gallardo *et al.,* 1998b; Moreno & Gallardo, 2002). In addition, in spite that the decomposition of litter (Table 2) is relatively fast, the N is retained by the decomposing litter (Gallardo *et al.,* 1998b), the P availability by plant is very low (Turrion *et al.,* 2000), and the stability of the humic substances (calculated soil-humus decomposition-constant is 0.026, Table 3) is high.

Fluxes and total balance of C

For a total balance of C applied to the study coppices, equilibrium in ecosystems is assumed in this type of approach.

The calculated total input of C (Table 4), in the forest ecosystems studied, would be the sum of input of DOC from bulk rainfall (50 kg C ha^{-1} yr^{-1}) plus C sequestered annually by permanent biomass (5.7 Mg C ha^{-1} a^{-1}), the result being 5.8 Mg C ha^{-1} yr^{-1}.

To calculate total output of C (Table 4) it is necessary to add the DOC lost by deep drainage (14 kg C ha^{-1} yr^{-1}), plus C lost by runoff erosion (soil particles, 120 kg C ha^{-1} yr^{-1}), plus C evolved (as CO_2) during litter decomposition (950 kg C ha^{-1} yr^{-1}). Other figures are mostly transferences (fluxes) inside the ecosystem. Thus, the result yields a total of 1.08 Mg ha^{-1} yr^{-1} in this chestnut coppice.

Thus, on calculating an overall balance (Gallardo, 2000), apparently the annual input of C into this forest ecosystem is always higher than the output (i. e., there is a net C sequestration), the excess being 4.72 Mg C ha^{-1} yr^{-1} at SMT.

Conclusion

This coppice studied acts as a net sink of C, resulting an annual sequestration of 17 Mg of CO_2 per hectare. Obviously, forest management (mainly, time-rotation) has strong influence on the C sequestration capacity of the chestnut coppices.

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